New Results from the Double Chooz Experiment

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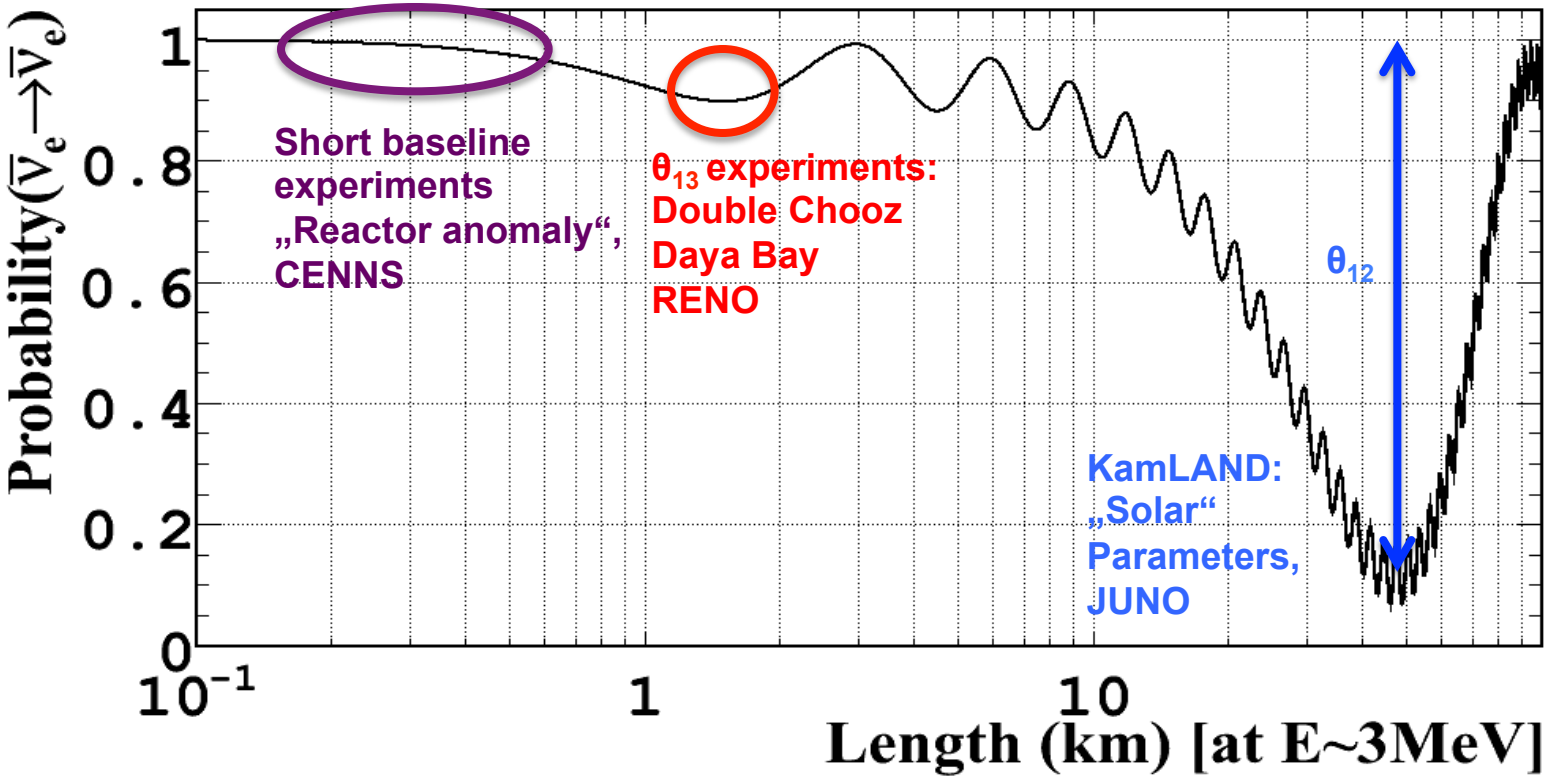
on behalf of the Double Chooz Collaboration

Neutrino mixing at reactors



$$P(\bar{\nu}_e \to \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2\left(1.27 \frac{\Delta m^2_{13}(eV^2) L(m)}{E_\nu(MeV)}\right)$$

Double Chooz Collaboration

Brazil

CBPF
UNICAMP

France

APC (IN2P3)
CEA/IRFU:
- **SPP**
- **SPhN**
- **SEDI**
- **SIS**
- **SENAC**

CENBG (IN2P3)
LNCA (IN2P3/CEA)
Subatech (IN2P3)

Germany

EKU Tübingen
MPIK Heidelberg
RWTH Aachen
TU München

Japan

Tohoku U.
Tokyo Inst. Tech.
Tokyo Metro. U.
Tokyo U. Science
Kitasato U.
Kobe U.

Russia

INR RAS
RRC Kurchatov

Spain

CIEMAT-Madrid

USA

Alabama U.
ANL
Chicago U.
Drexel U.
Hawaii U.
Notre Dame U.
Virginia Tech.

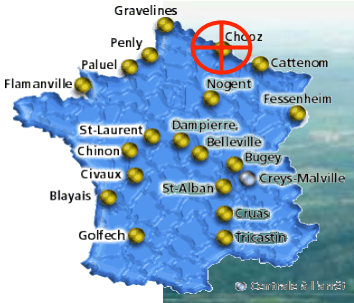
Spokesperson:
A. Cabrera (IN2P3/CNRS)

Project Manager:
Ch. Veyssière (CEA)

97 scientists 25 institutions (Americas, Asia, Europe)

doublechooz.in2p3.fr

Double Chooz site



Near detector (ND):
Data taking 01/2015

Far detector (FD):
Data taking 04/2011

415 m

1.05 km

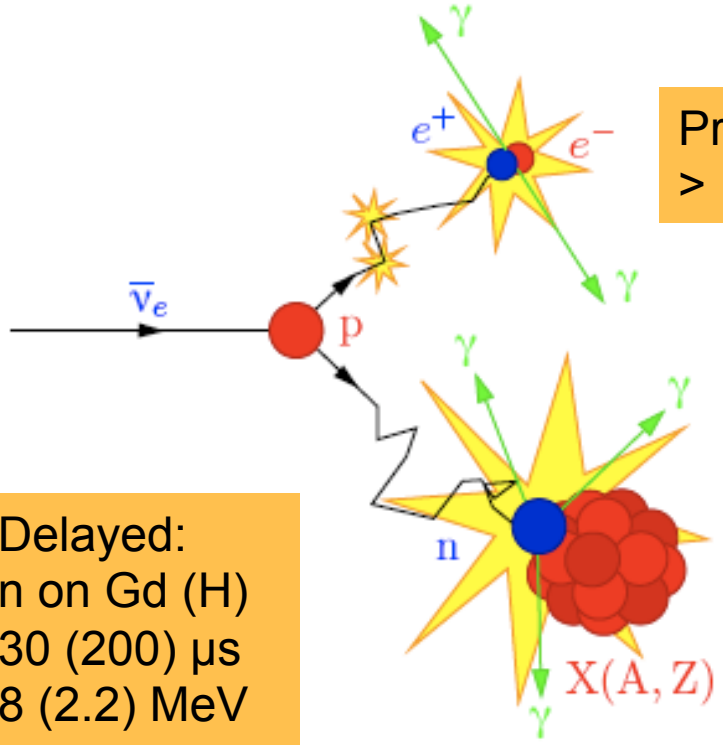
2 x 4.25 GW_{th}
≈ 10^{21} neutrinos/s

Reactor systematics cancelllation by simple geometry (effective iso-flux)

Neutrino production / detection

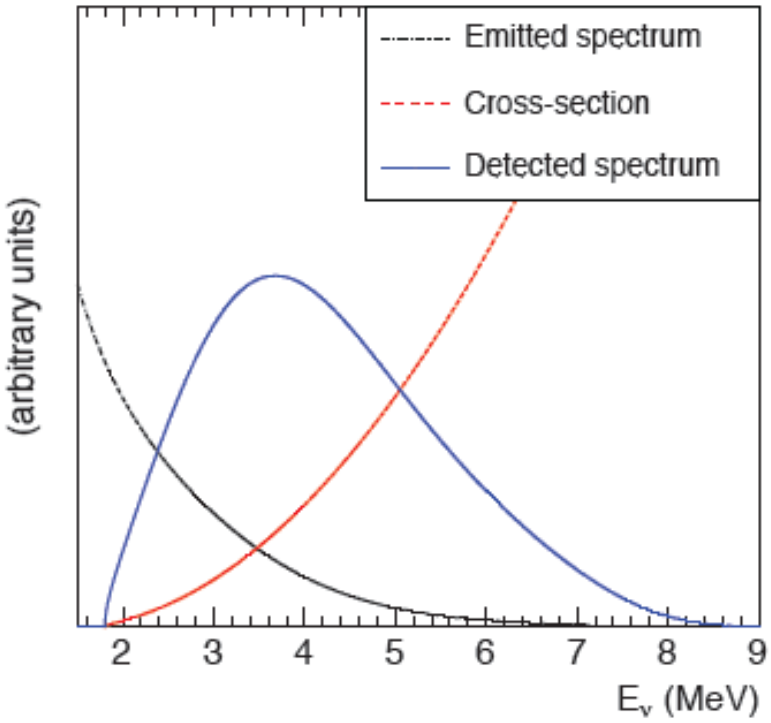
$$N_\nu^{\exp}(t) = \frac{\varepsilon N_p}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle} \times \langle \sigma_f \rangle$$

→ Mean cross section per fission (Near detector!)



Prompt:
> 1MeV

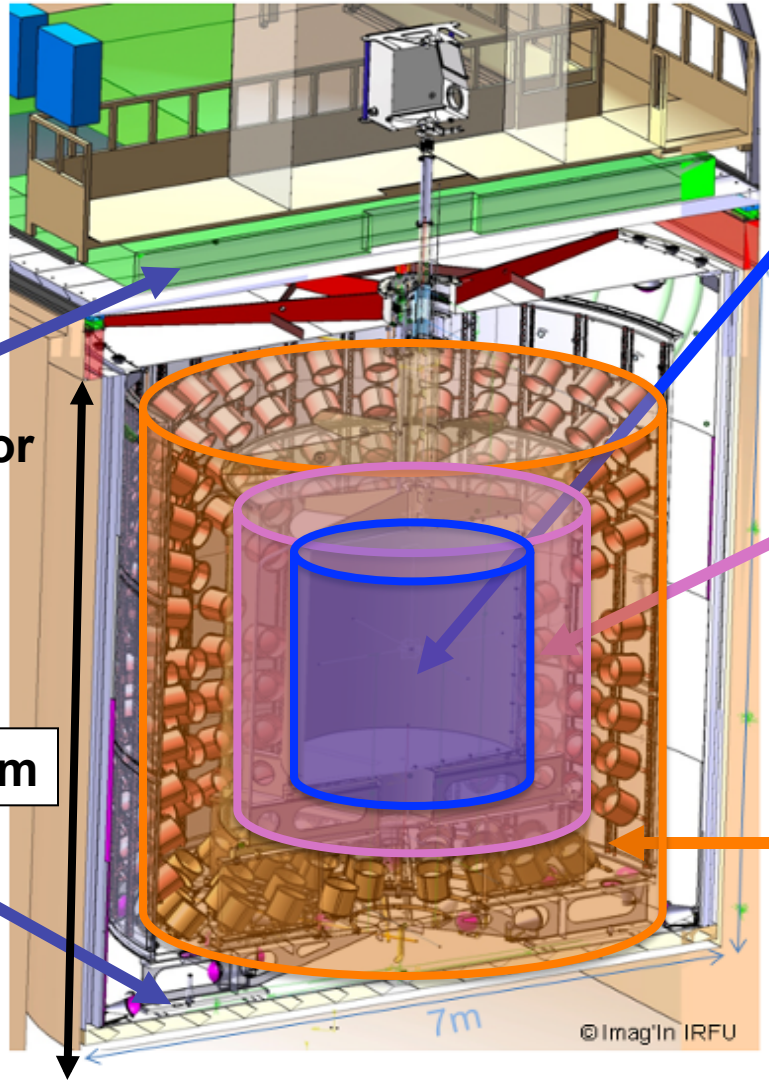
Delayed:
n on Gd (H)
30 (200) μs
8 (2.2) MeV



$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$E_{vis} = E_\nu - 0.8MeV$$

Detector Design



Outer Veto:
Plastic scintillator

Inner Veto:
- Steel
- 70 t LS
- 78 PMTs (8”)

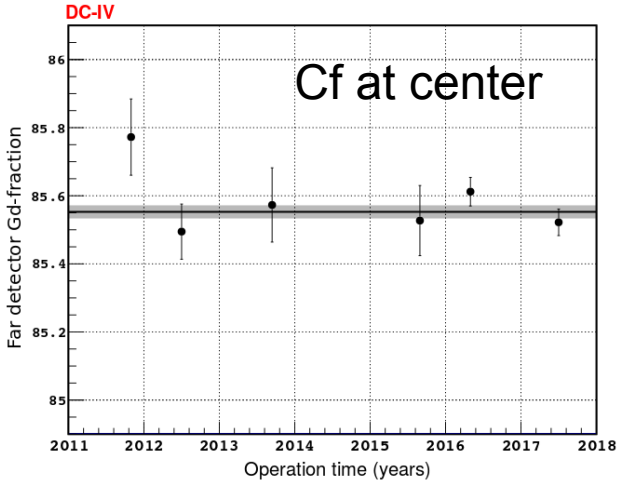
Inner detector:

Target (r = 1.2 m):
- Acrylic vessel
- 8.3 t Gd-scintillator (1 g/l Gd)

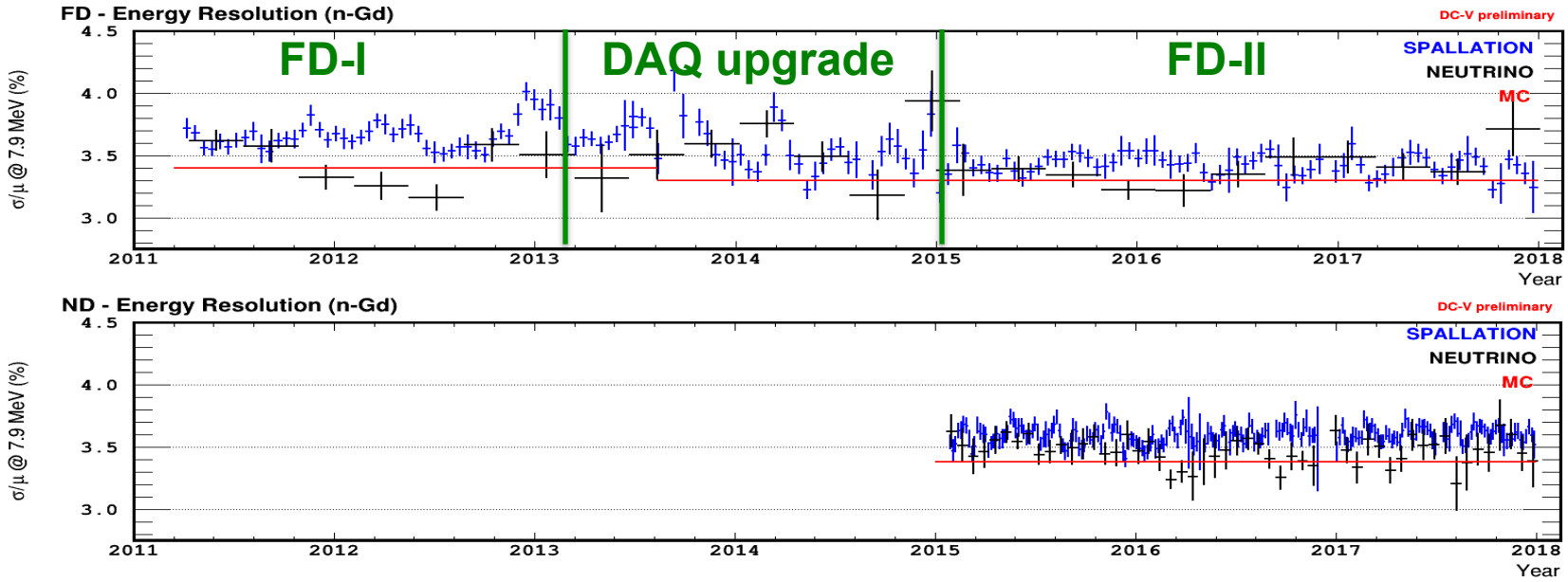
Gamma Catcher (0.55 m):
- Acrylic vessel
- 18 t liquid scintillator

Buffer (1.05 m):
- Steel vessel
- 80 t “oil”
- 390 PMTs (10”)

Scintillator stability

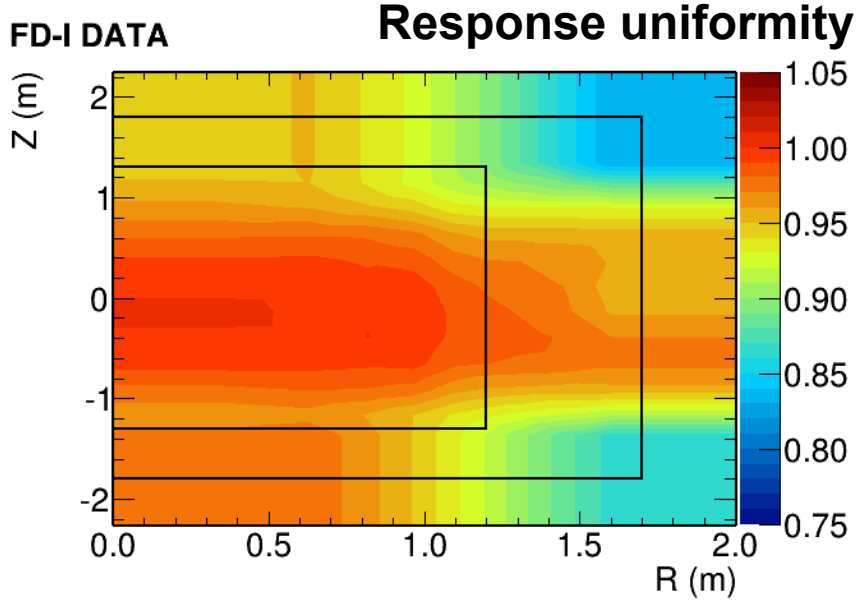


- Optical and chemical stability of Gd-scintillator (7 years)
- Gd fraction (center) stable on < 0.1% level

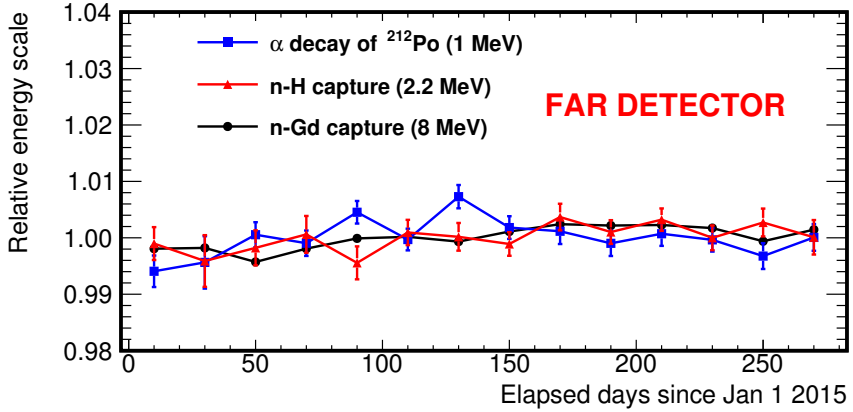


Energy scale

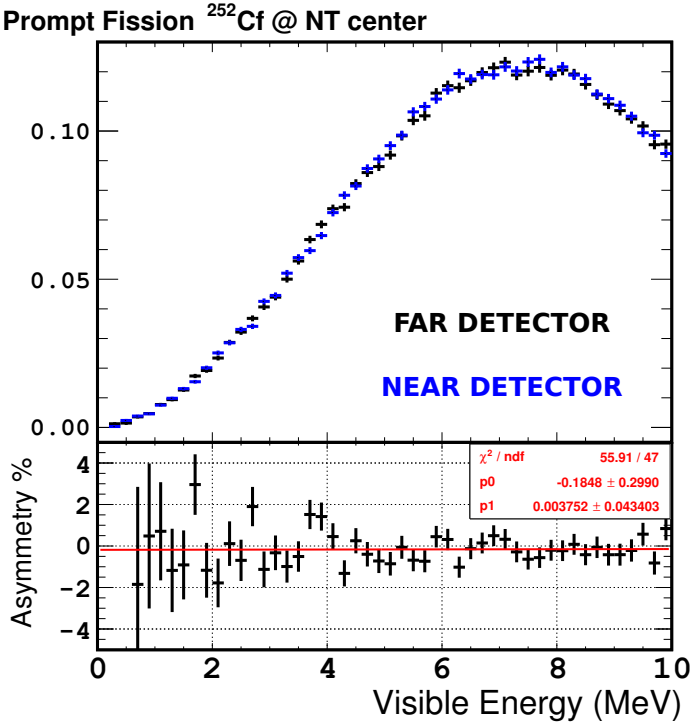
Response uniformity



Time variations

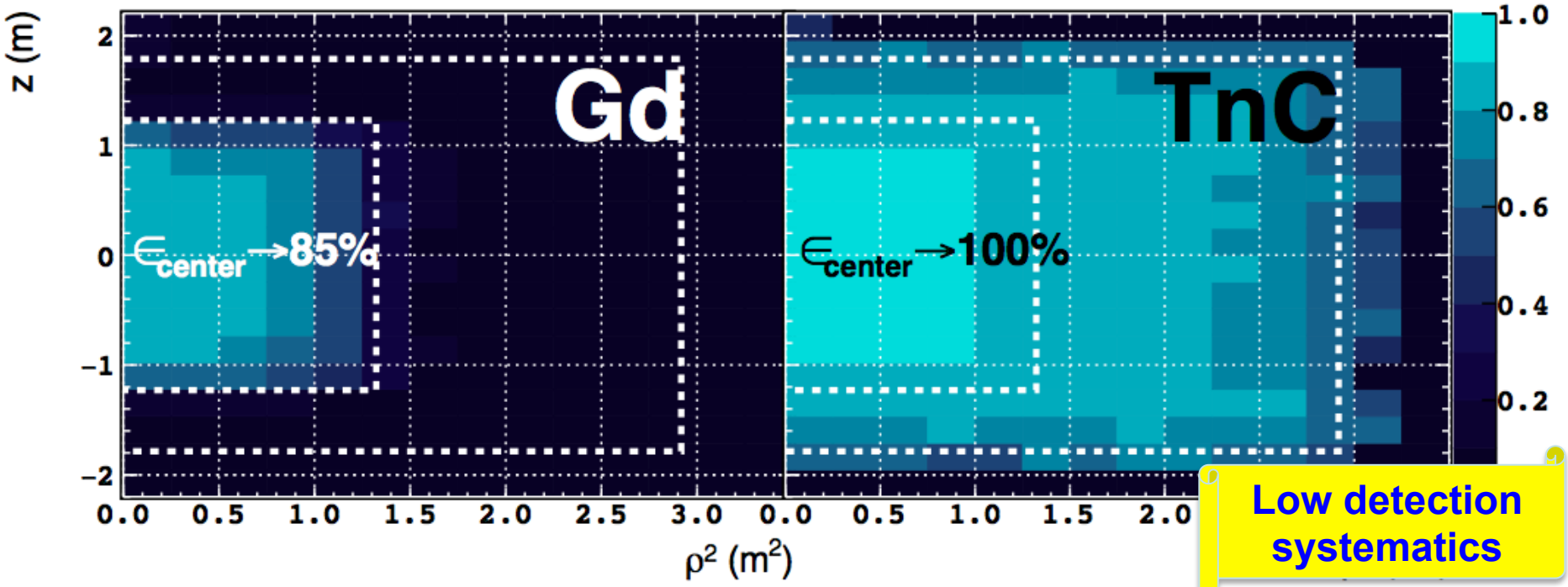


Very good Near-far agreement



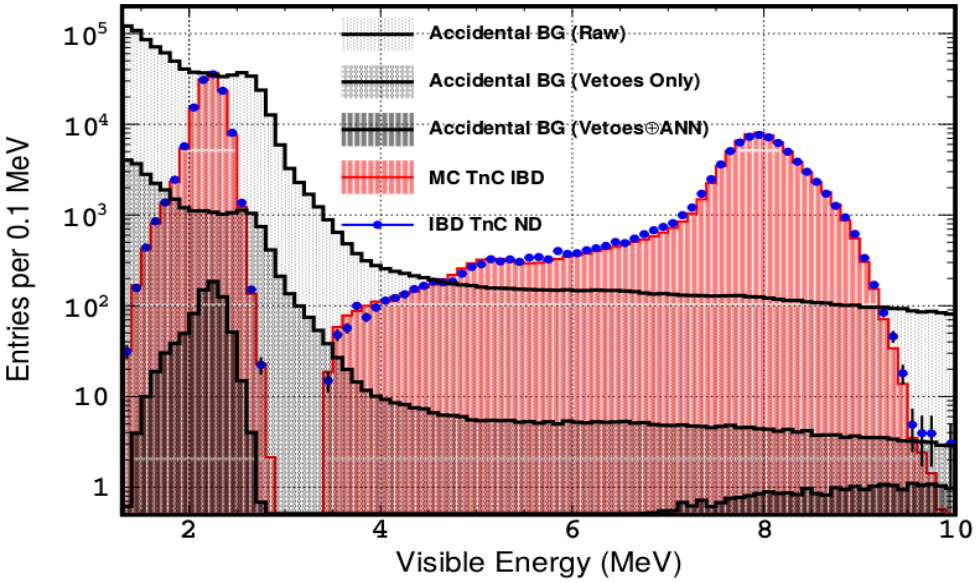
DC statistics / efficiency

„Small“ Gd-target (8.3 t) and „only“ two reactors



„Total n-capture“ (TnC) improves statistics factor 2.5!
(captures on Gd+H+C ➔ leak immune!)

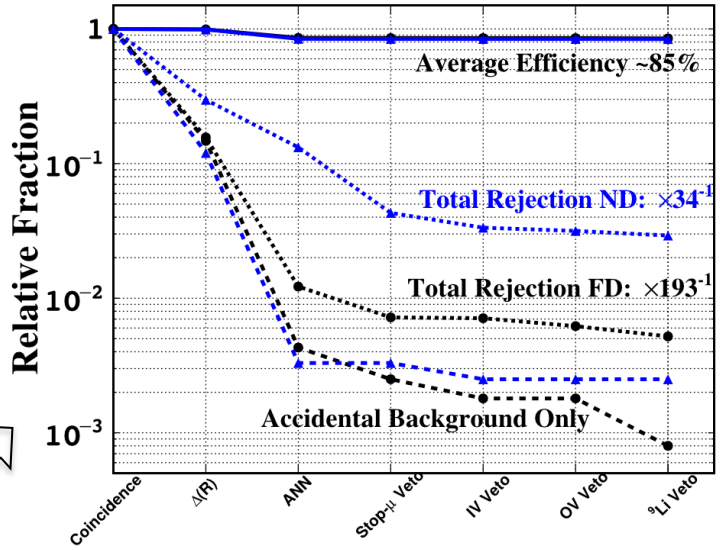
Background reduction



Delayed E spectrum (data and MC) before and after cuts

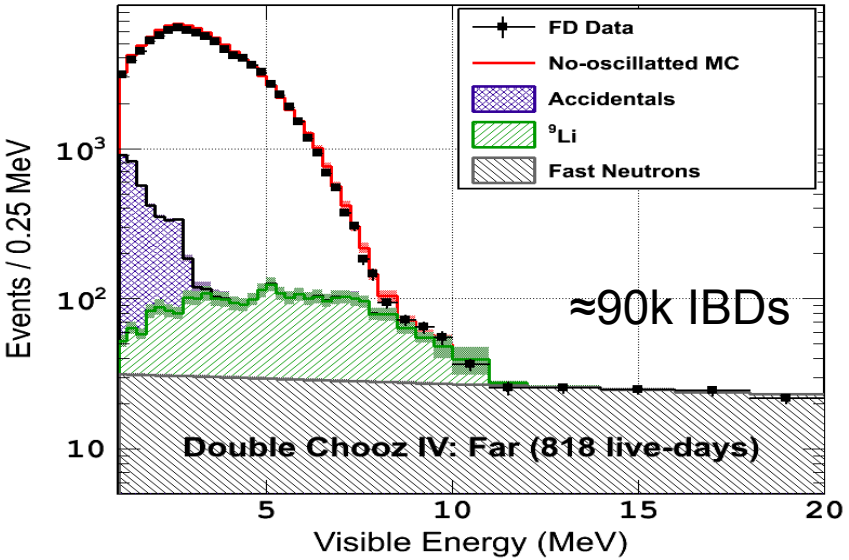
- Good data/MC agreement for IBD candidates
- Efficient background supression with cuts/vetoes

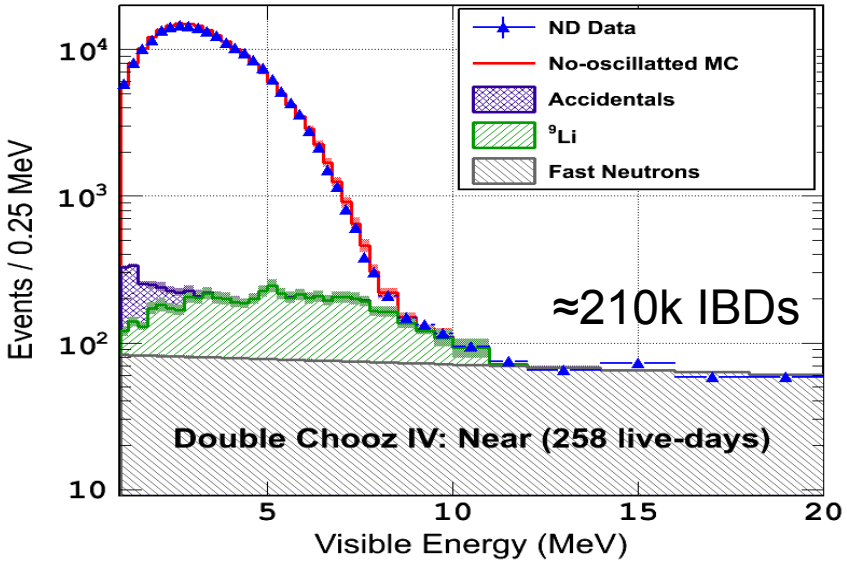
Cumulative rejection per cut



IBD efficiency and background rejection

Signal and backgrounds

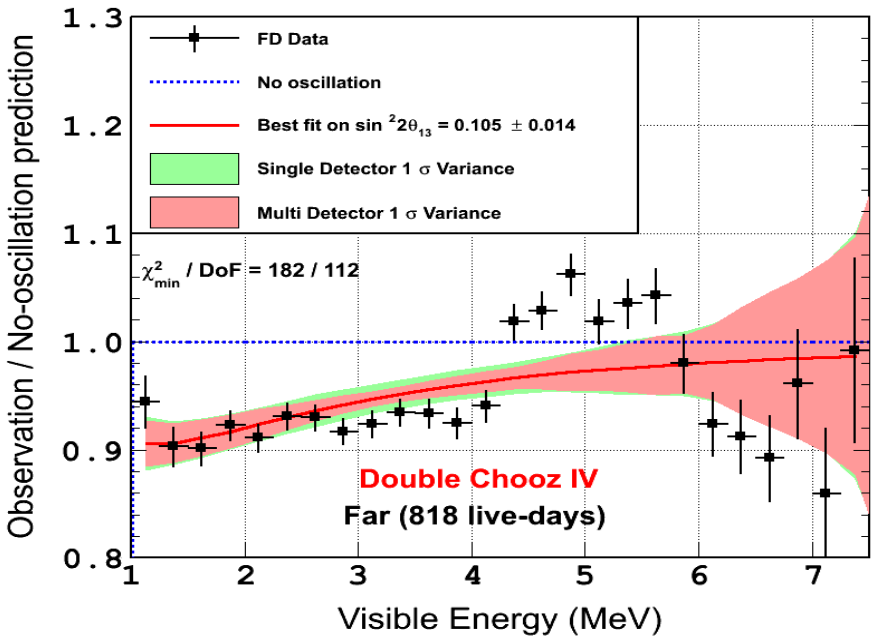


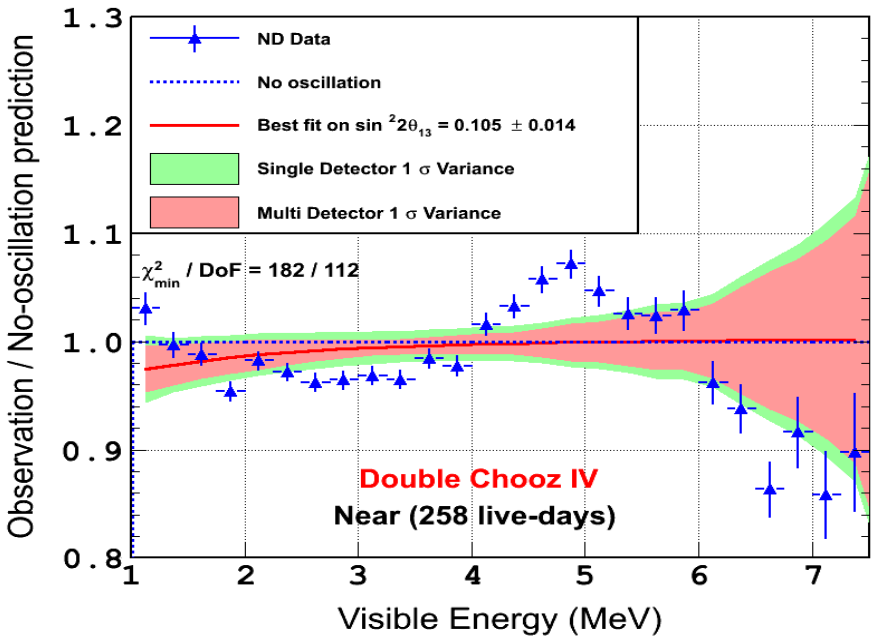


	Ev./day FD	Ev./day ND
IBD candidates	112	816
Cosmogenic BG (^{9}Li)	2.62 ± 0.27	14.52 ± 1.48
Fast n	2.50 ± 0.05	**20.85 ± 0.31**
Accidental BG	**4.13 ± 0.02**	3.11 ± 0.01

S/B > 10!

DC-IV fit results



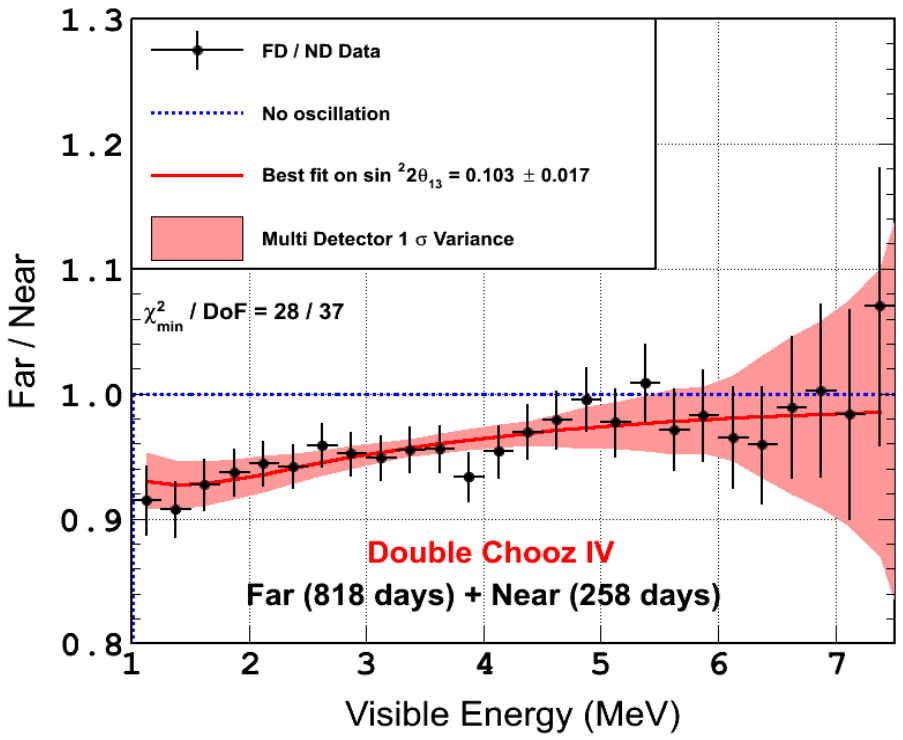


- Data-MC fit including Bugey 4 normalization
- **$\sin^2 2\theta_{13} = 0.105 \pm 0.014$** (stat.+syst.)
- Multi detector fit robust against spectral distortion

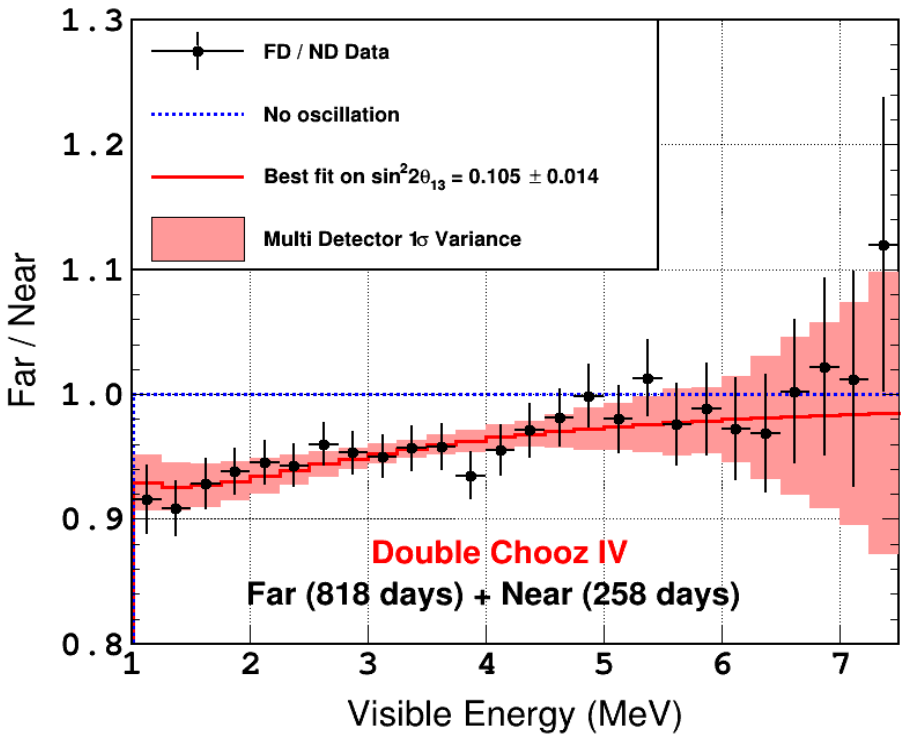
New!

Near to far ratio

Data/data



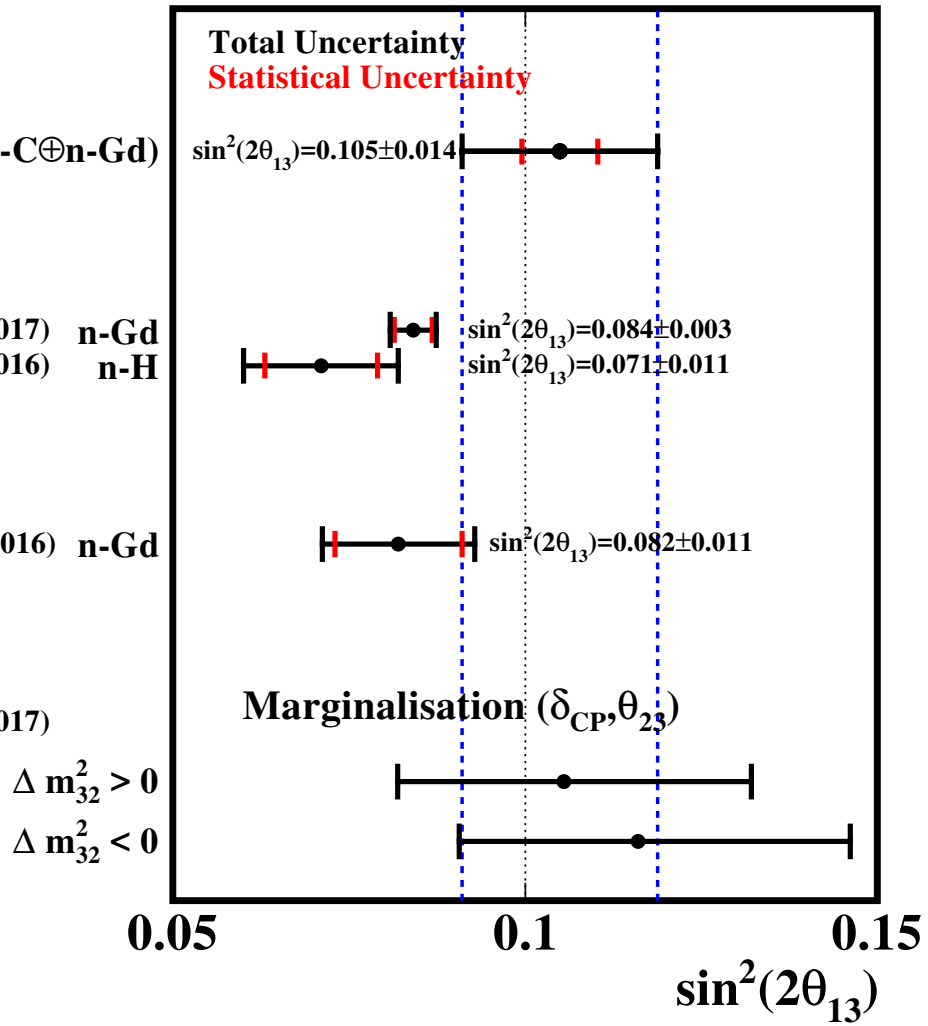
Data/MC ratio plot



Data to data result: $\mathbf{\sin^2 2\theta_{13} = 0.103 \pm 0.017}$

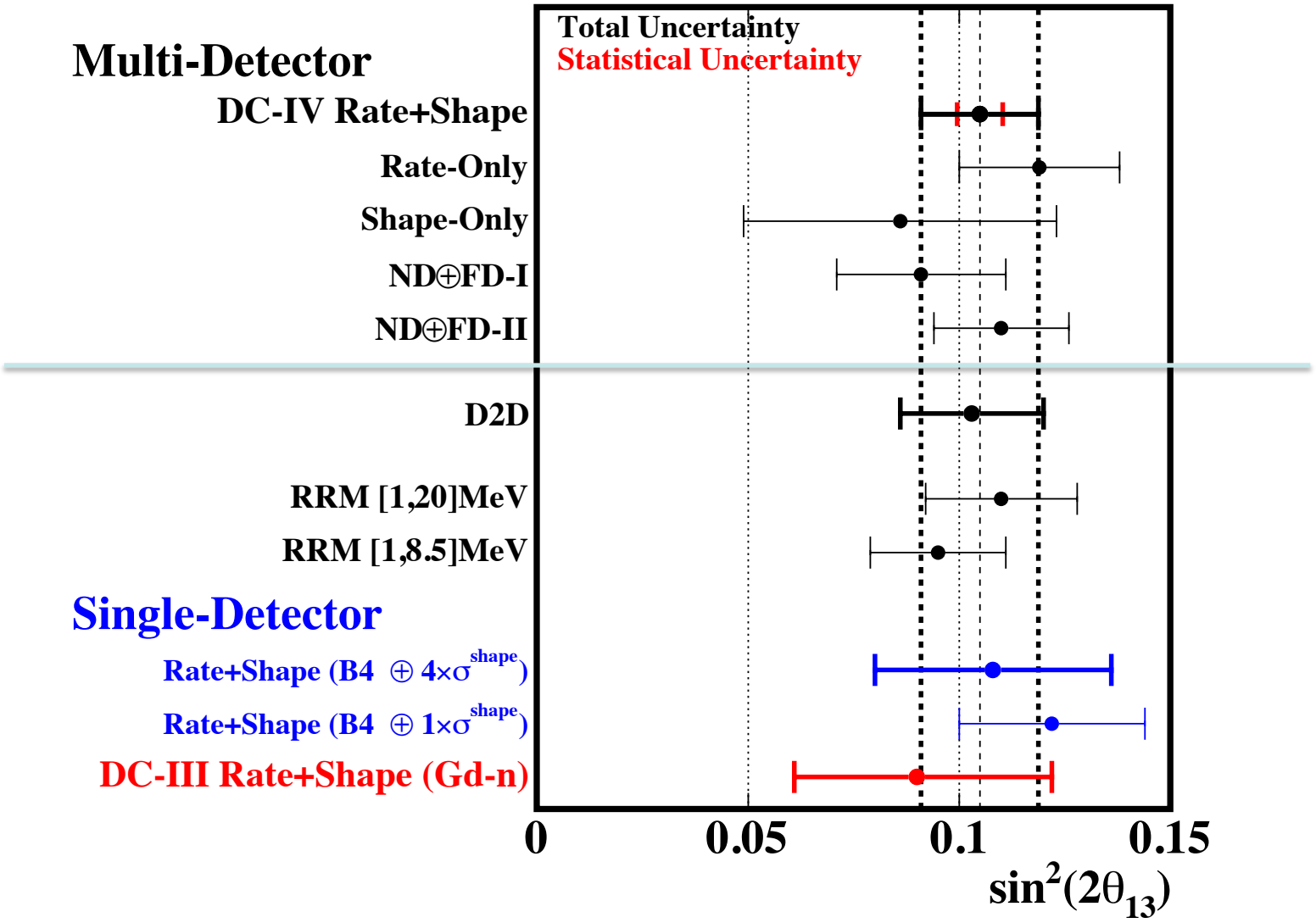
Result comparison worldwide

1.5 σ difference (systematics!)

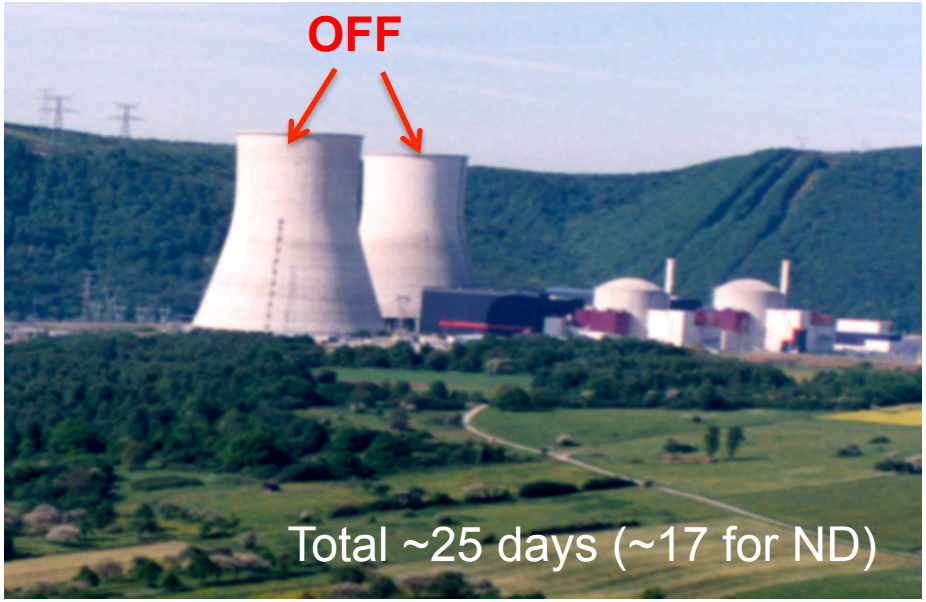


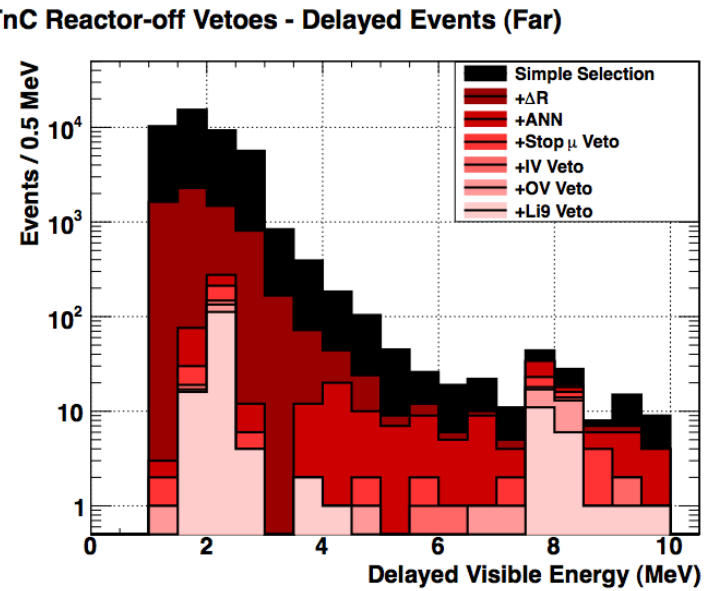
Two common DC/DYB/RENO workshops to discuss systematics

More DC θ_{13} fits



Both reactors off data



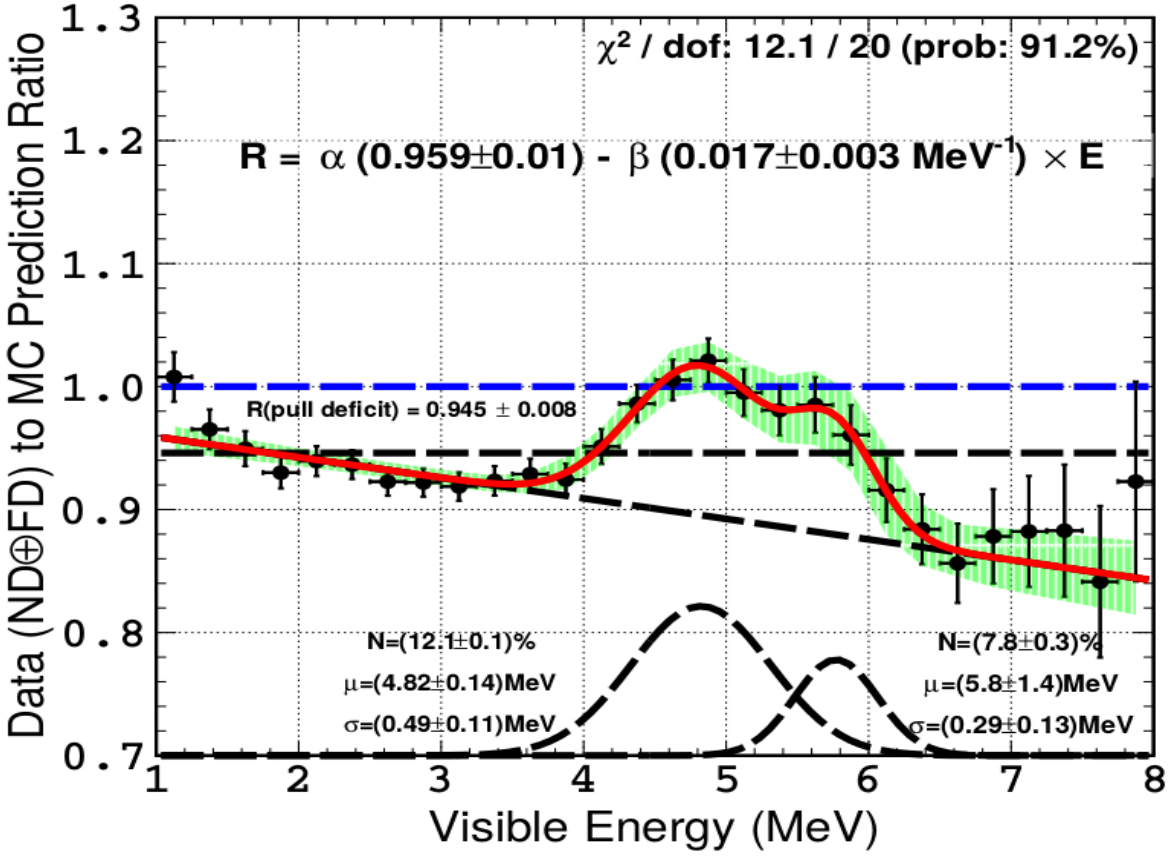


	ND (ev./day)	FD (ev./day)
OFF-OFF I (2012)	-	8.9 ± 1.2
OFF-OFF II (2017)	39.6 ± 2.5	9.8 ± 0.9
Rate+Shape values	38.5 ± 1.5	9.3 ± 0.3

Background understanding

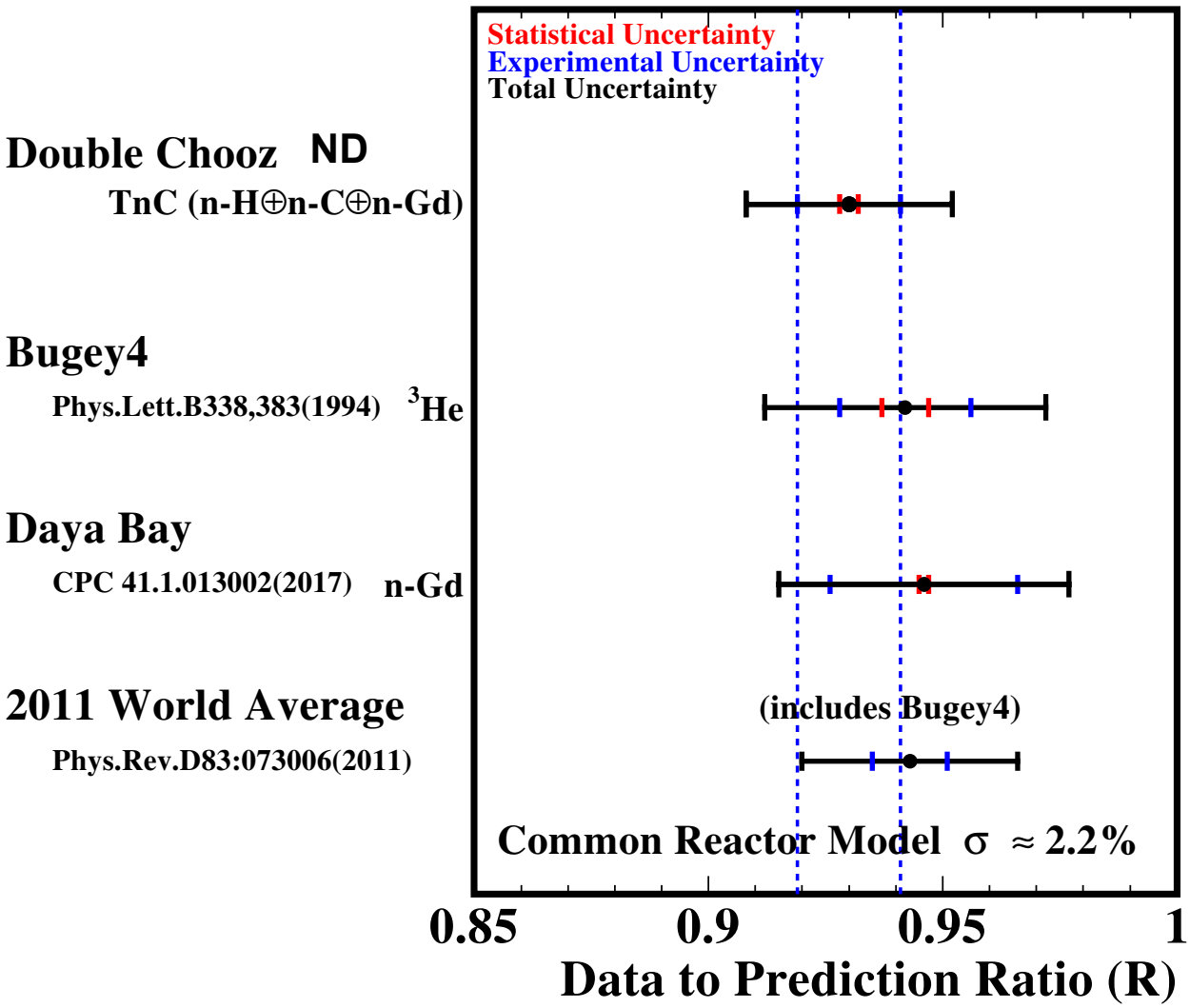
All numbers within 1 σ!

Spectral distortion



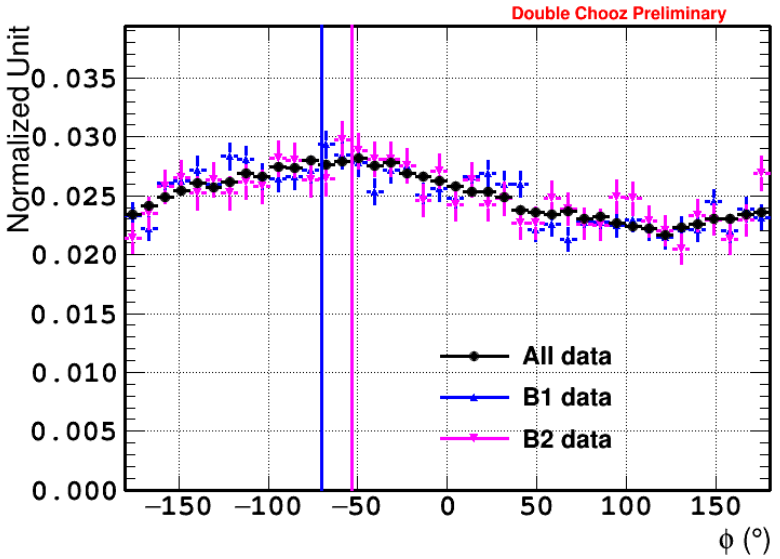
- Empirical fit: negative slope and empirical double peak
- Width significant larger than energy resolution

Data to prediction ratios



Publications / studies beyond θ_{13}

- Background studies
  (DC, PRD 87 (2013) 01110(R),
  DC, PRC 93, 054608, 2016)
  DC, arXiv:1802.08048)
- Cosmic muon characteriz.
  (DC, JCAP02(2017)017)
- Ortho-positronium
  (DC, JHEP 10 (2014) 032)
- Lorentz violation
  (DC, PRD 86, 112009, 2012)
- Scintillation waveforms
  (DC, JINST 13 (2018) P01031)
- PMT light noise
  (DC, JINST 11 (2016) P08001)
- Neutrino directionality
- Sterile neutrino studies



DC posters:

- T.Lasserre: Mo#159
- T.Bezerra: We#210
- D.Navas: We#205
- A.Oralbaev: Mo#199
- P.Soldin: We#207

Summary

- Double Chooz 2 detector data: early 2015 till end of 2017 (effective iso flux)
- Improved statistics with total neutron capture (low detection systematics)
- Good background control (S/B > 10): confirmed background model with Off-Off data!
- New result: $\mathbf{\sin^2(2\theta_{13}) = 0.105 \pm 0.014}$
- Spectral distortion: slope and 4-6 MeV structure
- Currently finalizing publication
- Sensitivity improvement: ≈2 more years of data and new measurement of target proton mass

In memory of...

Herve de Kerret
(spokesperson 2004 – 2017)

Sensitivity